

An Improvement Method for Swell Problem in Sulfate Soils that Stabilized by Lime

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Abstract: In this research low plasticity clay (CL) has to be mixed by varying percents of gypsum and after that this mixture would be treated with different amounts of lime, in two methods: regular application and Double application. The swell examinations would be done on these samples; and the influence of sulfates and mixing method on different quantities of swell will be taken into consideration. The results show that the presence of sulfates causes an incredible increase in the swell. This increasing also is at times much more than the thing that is revealed in unimproved samples; but in improved samples from Double process mixing method the quantity of the swell would be decreased in large volume in comparison with regular method.

Key words: Stabilization, lime, gypsum, swell, soil improvement, double lime application, sulfate, expansion, treatment

INTRODUCTION

The add of lime to clay cause several phenomenon's in soil like; plasticity index, raising of efficiency, resistance on survival in soil. Lime will show some chemical reaction with clay that causes some cemented minerals like: calcium silicate and calcium aluminates came to existence. The quantity or ratio of those minerals increases during the time; and also the resistance of the soil rises.

Although lime has important affections in clay improvement, but in special conditions, like the soil that comprise soluble sulfates, or when the soil is in the presence of sulfates that other different resources like the water in It's an environment comprise them, besides the use of lime doesn't have any affection, the secondary minerals come into existence; like: Ettringite and Thaumasite. Because of chemical reactions that would happen between clay, lime and sulfates; that those minerals intensively expand because of absorbing water and these special circumstances cause different problems like distractions in surface building of roads; that the weight of the structure is light .

Recently many unsuccessful experiments have been observed about improvement of some kinds of soil by lime in America and England^[1-3]. In researching the experts recognized the attendance of solving sulfates specially calcium sulfate in the soil of those regions and also the presence of minerals likes Ettringite and Thaumasite in improved soil was important. Although the calcium sulfate is the least solvable sulfate but it is the most common sulfate in the soil and make Ettringite mineral at the attendance of lime and clay.

The calcium sulfate merely doesn't have any serious danger about expanding or swell in the soil

because the calcium sulfate in soil would be crystallized by absorbing of water and usually have two molecules in a permanent situation. It's possible that in the natural process for establishing calcium sulfates, many expanding chemical processes come to happen. The oxide of same sulfates like: pyrite and their combinations with the exist carbonates in soil like: calcite cause calcium sulfate. This reaction is self-expanding because of absorbing two molecules of water; and if a kind of soil like that has been stabilized with lime because of making Ettringite; the rate of swell will arise. Therefore the improvement of a kind of soil that comprise sulfate or the possibility of sulfate attack is usual in those kinds of soil, by lime is very dangerous and needs much more investigation to the act of those kinds of soil in a long time. For instance many of pavements can be seen that have high quality in first six-month or two years, but when the mentioned circumstances were available, the soil will swell intensively. So for improvement of these kinds of soil, we have to look for other solutions. One of the suitable solutions in this field is the effect of Double lime application that is under survey in this project. The Base of this method is established on this reality or idea, that soil has to be mixed with lime into the process and during this examination in the short interval that is between add of lime in the first and second process, a ratio of swell reaction and making Ettringite mineral would be done, that in this period of time because we don't have any affection of loading or structure weight on the surface of soil, the swell problem won't be Shown. Then to add of lime on second level, the compaction process of soil would be done and the soil improvement will begin.

In this project the affection of mixing method to optimize a variety of properties that concern about the kinds of soil that comprise sulfates which is improved by lime has been considered. In this research the results that are taken from the Double lime application method and relate to the swell of samples will be compared with results that are reached by the regular method. The changes in the volume of lime and sulfate from zero to nine percent prepare the possibility to recognize the optimum quantity of lime and sulfates in different cases.

The double lime application is based on this supposition that the adding of the first part of lime to a sulfated soil prepares a special situation for making expandable minerals like Ettringite and Thaumasite; and cause complete swell in soil. But the add of the second part of lime and doing the compaction process due to perfect pozzolanic reactions, cementing process and at last increase in resistance soil; so any delay or interval between those two mixing process is important.

In Double process method it is important to have information about the rate of sulfate in the soil and also their sources. Because the examinations related to the rate of solvable sulfates in the soil, so they are not useful to understand the whole quantity of sulfates in the soil. Perhaps sulfates penetrate to the improved part of the soil because of capillary phenomenon that begins from beneath layer of the soil that is not improved or another reason that is because of a rate of sulfates that may be washed from the soil environment and take apart in several reactions that mentioned.

In Double process method beside the default that originate from not doing the essential specification and anticipation of real rate of sulfate, using from lime more than the specific limitation may be caused that the soil miss the capability of taking a part in pozzolanic reactions; and this additional lime is being washed by water current and by moving toward the beneath layer will react by unimproved layer and caused to make Ettringite in this layer and transmit the swell problem to the down layer. So in this method selection of the optimum percent of lime is very important.

By taking consideration of the above several mentioned problems, double lime application is useful when the natural soil comprises a low capacity of solvable sulfates and also should have the privilege of lack of sulfide minerals^[4]. Anyway, the Double lime application is affectionate if there is enough time interval between two processes and use for more than optimum quantity of water in the first process of adding and low percent of lime.

If the refereed conditions take into consideration, it seems that we can stabilize the soil by the rate of solvable sulfates up to 7000 PPM with Double process method^[4].

In laboratory research that Frries and his assistants had done in 1991^[2] on three kinds of expansive soil that comprise sulfates and was picked up from Texas,

California and Colorado, the results show that the Double process method caused an incredible increase in resistance of improved soil and also caused swell potential improvement in improved soil by lime.

The achieved results from electronic microscope show that in improved samples by Double process method a little quantity of Ettringite can be seen.

The scrutinizing in the process of chemical reactions between clay minerals, lime and sulfates that at last cause to make expandable minerals like Ettringite and Thaumasite consist of different process; that you can see the details in the reference^[5].

Laboratory study: From the previous discussions we come to this conclusion that the use of lime is one of the cheapest suitable solutions toward the improvement of Clay. But if the soil comprises sulfates, the use of lime in direct or regular method, increase the appliance of swell and destruction in comparison with improved soil. In this project, this action is attended and use of double lime Application, introduced by means of efficient and useful method for sulfated soil stabilization. In this section the laboratory examination researches and property of materials would be presented.

Materials and their properties:

Clay: Only some kind of the soils, that the quantity of clay mineral in their structure is in an acceptable range which get a part in pozzolanic reactions, can be effective in stabilization with lime. Approximately all kinds of clay minerals can react with lime in a good case because of Silica and Alumina that is in their structure. But a kind of soil with higher plasticity property in a much more effective in long time reactions by lime; and the affection of improvement by lime in those kinds of soil is higher.

The ratio of Alumina to Silica in clay minerals is different. Among the several kinds of clay minerals, because Kaolinite has a large volume of Alumina in comparison to the other clay minerals like Montmorillonite and Illite beside if it comprise sulfate and has been improved by lime, then we can say that it has much more affection in making Ettringite mineral in comparison with other clay minerals^[6].

In order to better estimation of sulfate affection on improved soil by lime, the selected soil should have those properties:

1. At least the attendance of 10% of clay minerals is necessary. (To do pozzolanic reactions)
2. The swell potential should be in low range (in order to find out the difference between the swell that come into existence from clay lonely and the swell which originate from the appearance of Ettringite in improved clay).

Table 1: Soil property that is used in this research

Natural moisture	W	7.5
Finer than two microns		30
Density	GS	2.75
Shrinkage limit	SL	15
Plastic limit	PL	17.4
Liquid limit	LL	30.4
Plastic index	PI	13
Activity	A	0.43
Swell index	SW (free)	2.85
unified classification	UNIFIED	CL
AASHTO classification	AASHTO	A-6(10)

The soil sample that is chosen for this project is a kind of clay from eastern south of Tehran that is simply available and use of this kind of clay is very common in buildings.

The General properties of this soil that achieved in ASTM standard are shown in the Table 1.

Lime: Although the quick lime has large capacity of (Cao) in comparison with hydrated lime and It cause to have much more affection in improvement of soil, but because the use of Hydrated lime Contain more security, the application of that, is more in industry. About chemical Activities we can not find any difference between those two kinds of lime. Usually 4% of hydrated lime weight is equal to 3% of quick lime. The only difference is the volume of water to hydrate that the quick lime needs more water. The disposed lime in this project is ALBORZ industrial hydrated lime in 25-kg packs; that it's not vibrated unit weight is 550 kg m⁻³.

Calcium sulfate (gypsum): The calcium sulfate in nature exists in two different types^[7]:

1. Hydrate calcium sulfate or gypsum (CaSO₄+2H₂O)
2. Dry calcium sulfate or anhydrite (CaSO₄)

As introduced above it was referred that the Anhydrite would be crystallized gradually by absorbing of two molecules of water and change into gypsum. In this process we encounter with a high range of swell in soil. Sometimes this expanding or swell causes heaving of ground surface up to 6 m^[7].

The calcium sulfate that is used in this project is the gypsum Saveh region that could be found in 20-kg packs in the bazaar.

Water: If water comprises a large volume of soluble salts, the progression process of reactions would be affected. So it's better to use distillate water in examinations. We use for drinking water of Tehran is this examination because the rate of soluble salts is very low in this water and it won't be expected that the examination results get affected from this low quantity.

The making process of samples and essential examinations: The examinations in this project distribute in to three categories:

1. The primitive examinations of disposal materials (majority soil).
2. Compaction examination with a mixture of different percents of lime, gypsum and soil.
3. Swell measuring examinations about untreated samples and treated samples at regular and double lime application.

From the aspect of lime mixing the samples distribute in to three major sorts:

- * Limeless samples
- * The samples that mix by lime in direct or regular method
- * The samples that are produced by a Double lime application

From a total number of 28 samples, 4 samples are limeless, twelve samples are made by regular mixing method and twelve samples are made by Double process mixing method.

In each Group, 4 cases in taken are in consideration from the aspect of a gypsum percent in their structure:

- * Gypsumless soil
- * Soil with 3% of gypsum
- * Soil with 6% of gypsum
- * Soil with 9% of gypsum

For each following case, 4 samples with 0, 3, 6 and 9% of lime from total weight are made.

Swell examinations: The swell examinations are based on standards of ASTM-698-B and details with a sampling process in two methods and also moisture controlling of samples are delivered in reference^[5]. The regular method samples after preparing in mold and Double process method samples after one week from the time that primary mixing have been done and come to an ideal mood for 28 days, would be put in water which its temperature is about 14-16°C, then the rate of swell has been read during the time.

In limeless samples but specific percent of gypsum, the measurement of the swell would be done just at 96 h, because after this period of time the swell will stop.

RESULTS

A. Limeless samples: The samples in this research would be prepared in optimum moister limitation with approximate fault of 1.5% to minimize the rate of swell that originate from compaction and internal structure of soil^[5] and the role of Ettringite and Thaumassite minerals in swelling flourish better.

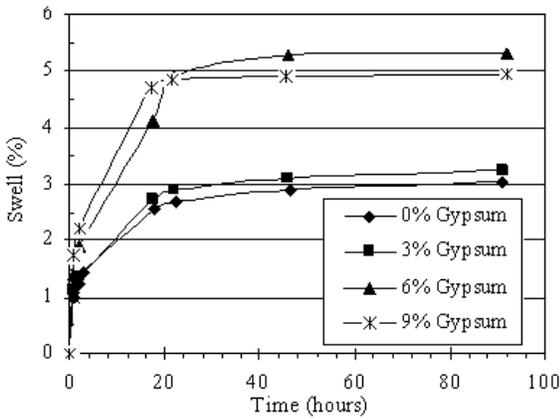


Fig. 1: Swell-time curve for limeless samples

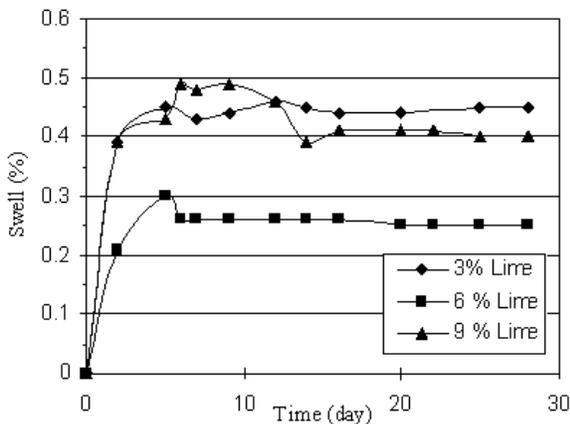


Fig. 2: Swell-time curve for gypsumless in regular method

Figure 1 shows the results of swell changing in front of the period of time for limeless samples in different percents of gypsum this measurement take 4 days. We can see from this curve that the rate of swell changes, after 24 h from beginning of saturation will decrease the intensity and after 96 h that the percent of saturation in a samples increase from 86 to 95%, the rate of swell changes come to zero. Also we can see in this curve that any increase in the percent of gypsum cause increase in the swell. The major reason for this conclusion is the absorption of anhydrite minerals in gypsum that they can complete their crystallization by this action, besides this process comprises swell in soil structure. It's a reality that the quantity of these minerals will rise with higher percents of gypsum.

It's clear that the clay minerals can't lonely make a new chemical reaction by gypsum minerals that cause of more absorption of water. So the attendance of gypsum doesn't have any affection in the rate of day minerals and clay minerals do the necessary swell even in the presence or absence of gypsum and any of them has a private swell that is independent from the other

one physical action. And the total rate of swell in each moment is added of clays swell and gypsum swell.

B. Improved samples by lime in regular mixing method:

It's a long time that the experts have understood the role of lime in reduction of clays swell. This reduction in expansion is basically because of urgent reactions under affection of unit capacity ion replacement like: (sodium, potassium) that exist in clay and Double capacity calcium ions that exist in lime and something long time Pozzolanic reactions. As we are familiar with clay minerals the existence of sodium in clay mineral of Montmorillonite cause higher swell in comparison with Illite that comprise potassium. To add lime into the soil cause momentary reactions (Cation exchanging) to happen in the first moments. The add of lime cause some changes in the soil properties and its swell will reduce intensively. In this research the interval between the mixing of soil and lime and the compaction time is one hour to give enough opportunity to the soil to have momentary reactions.

The momentary reactions between soil and lime cause reduction in plastic index of the soil, so the Efficiency of soil will arise. The attendance or not the presence of gypsum doesn't have any affection in momentary relations. So if the target of soil improvement is just being increase of soil Efficiency we can improve the soils that comprise gypsum by lime, but if the swell has to be taken into consideration we should be alert of swell reaction between gypsum, lime and soil.

B-1. Gypsumless: According to the Fig. 2 the add of lime to the gypsumless soil cause a large reduction in It's swell and the swell will decrease from 3% in limeless soil to 0.5%. It can be realized that the rate of swell came to maximum range in first 4 days and then it remains constant. Because of laboratory faults like the imbalance of the CBR mold in order to create a flat area for placement of gage in each measurement of swell, we can see same defaults and changes in quantities of swell. It's also important to know if plastic index of a kind of soil is higher than other kinds, the quantity of lime that is necessary for decreasing swelling and lime affection shows itself better. So because the soil that is used has low plasticity (PI=13), the increase of lime quantity doesn't have major affection in swell reduction. As it can be seen in Fig. 2 the lime increase from 3 to 6% cause an approximate decrease of 0.2%.

B-2. The samples that comprise gypsum: The improved samples that comprise gypsum with regular mixing method have fantastic swell even too much more than unimproved samples. Swell-time curves for adding these samples with different percents of lime and gypsum have been shown in Fig. 3-5. All of these curves approximately follow a same process and show that during a period of time the of swell will increase, but gradually the change rate of swell decrease.

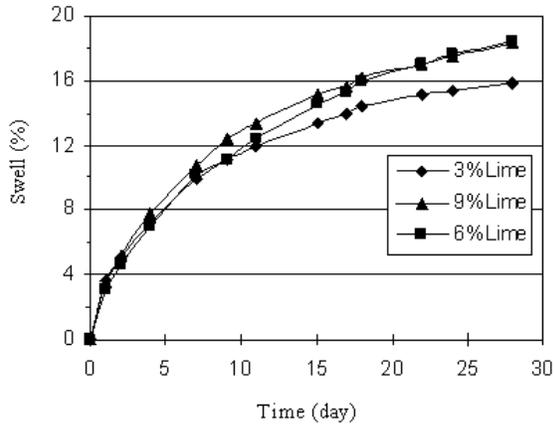


Fig. 3: Swell-time curve for the samples with 3% of gypsum in regular method

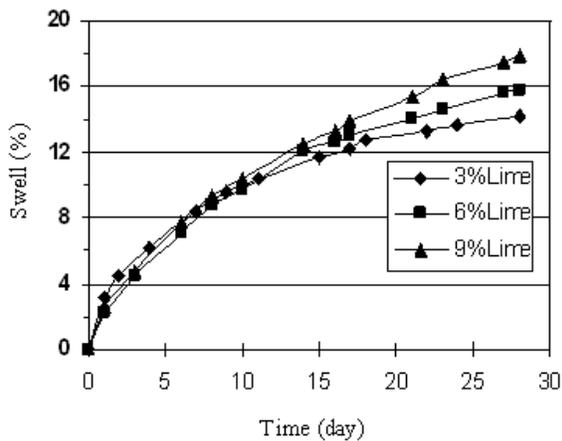


Fig. 4: Swell-time curve for the samples with 6% of gypsum in regular method

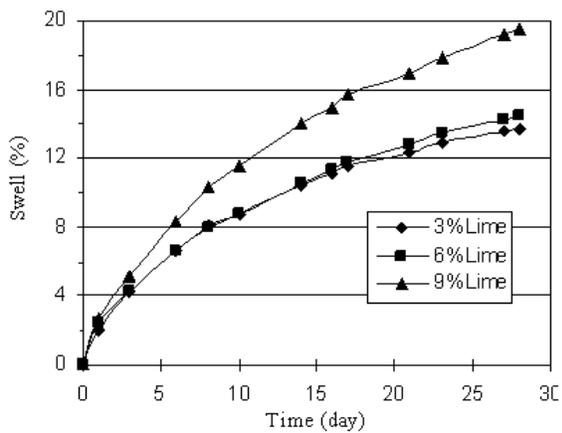


Fig. 5: Swell-time curve for the samples with 9% of gypsum in regular method

Also results show that after 28 days the samples still have the capability of more inflation. The examination

results of the swell are shown in Fig. 6 that is an improvement of lime and gypsum percent. All of the samples are prepared by regular mixing method; and major affection, of this method; and gypsum affection in return in order to increase swell can be achieved by comparing of limeless samples and samples which comprise lime. Also from the aspect of gypsum affection it seems that any reductions in gypsum quantity cause a fellable decrease to swell. (Except the sample No. 16 with 9% of lime and 9% of gypsum that it's swell is more than other samples; that it's possibly because of examinations defaults.)

The Fig. 6 also show that the gypsum attendance even if it's percent be low or high, cause intensive swell in samples; it means that even a low percent of gypsum also can make a high range of swell under affection of reaction with lime and clay. It also can be seen that increase of lime percent cause increase in sample swell; and also in lower percents of lime the rate of swell increase will raise; and by the increase in its percent the rate of these changes will decrease. It seems that the reason of swell growing, because of lime increase, depends on lime role in making Ettringite mineral. Although gypsum samples have swell percent less than 0.5% in attendance of lime, the gypsum presence cause extreme swelling increase approximately 14 or 20%. These swells increases; show that the regular mixing method by lime is extremely not an efficient method in swell reduction of samples that comprise gypsum. According to the Fig. 6 it's not possible to introduce any specific boundary by means of dangerous sulfate limitation in order to improve the soil by lime; the existence of sulfate in any quantities is dangerous. If we want to introduce a limitation for sulfates we should take into consideration the quantity of clay minerals and lime minerals. But according to the results the maximum limitation of gypsum in 3% and can cause a high range of swell in attendance of 3% of lime that is common rate in soil improvement by lime. Although the soil that is used in this research has low plasticity property but extreme swell that can be observed because of swell minerals like Ettringite and Thaumasite.

C. The samples that are improved by double lime application: The interval between mixing and compaction has a basic role in swell reduction. Of course this halt cause reduction in dry unit weight, that it can affect the decrease of soil swell potential but in comparison with the swell that originate from chemical reactions between clay, lime and gypsum this affection is low.

A double mixing process method like regular mixing method to some extent, but double mixing process method has a delay in its blending time. The only difference return to the suddenly add of entire of lime to the soil in one process method and the mixture will be compacted in a short period of time.

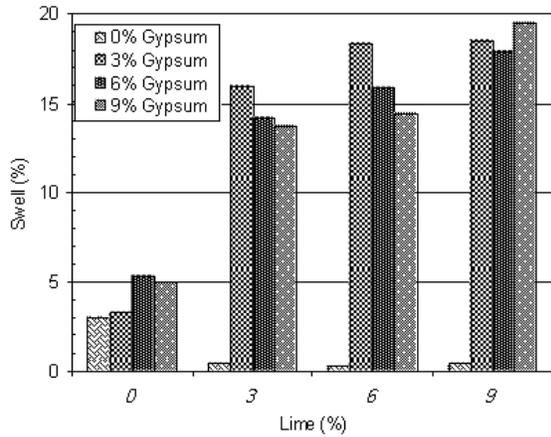


Fig. 6: Change of swell rate inverse of different quantities of lime and gypsum in regular method

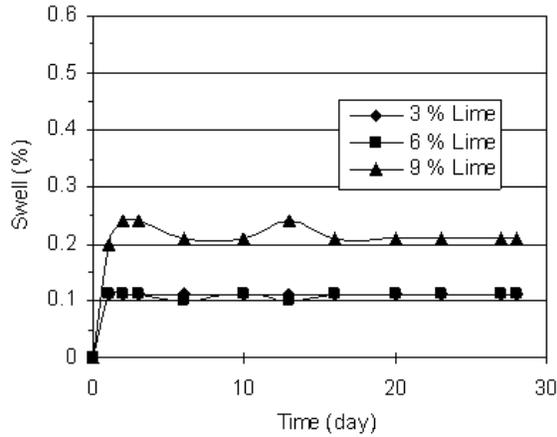


Fig. 7: The Swell-time curve for the gypsumless sample in double process method

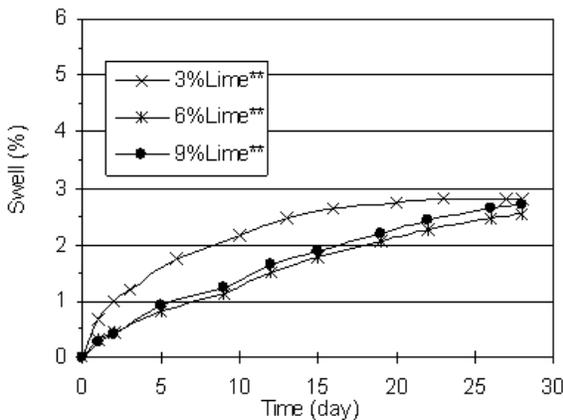


Fig. 8: The Swell-time curve for the samples with 3% gypsum in double process method

But in double process method half of lime add in the first and half of lime will add after one week, then compaction will be done.

In the double process method, because the area condition is suitable in the interval between mixing and compaction for making Ettringite and a percent of clay with lime and sulfates that exist in the sample use to make this mineral and Its issue is the swell that happen in soil structure. So after compaction the sample shows little trend to swell.

C-1. Gypsumless samples: In Fig. 7 there is a curve about the swell change in front of time for gypsumless soil in the Double lime Application. According to Its results we can see that the Double process method causes more swell reduction in comparison with regular method; as we can see that the swell for all percents of lime is between 0.1 to 0.2% that can ignore that. The reason for this reduction is majority under affections of cementing and also pozzolanic reaction (in compaction interval) at a reduction of sample dry unit weight. It's also possible that the cementing process of granules after compaction also has a role in swell reduction; but distinguishes of this affection not possible in achieving results. The major affection of Double process method is clear in the samples that comprise gypsum that will be mentioned later. Similar to the common method results, It seems that an optimum percent exists for lime that in this range the samples swell come to minimum quantity.

C-2. The samples that comprise gypsum: In Fig. 8-10 the curves show the swell for samples that comprise gypsum in front of time. The results show that by passing time the quantity of swell increase but its rate decrease gradually and in 28 days major part of samples swell are done and approximately all of curves follow the same process.

In Fig. 11 we can see a summary of final swell results for different cases that increase of lime or gypsum in different samples doesn't have considerable affection in swell changing. But the attendance of gypsum in improved gypsums samples by lime in comparison with gypsumless samples case swell increase that reveal this reality that still we have some swell minerals in Double process method. But the measured swell are too much lowers that quantity that relates to the regular method and also those relate to the unimproved soil.

Comparison between Fig. 6 and 10 show the important role of mixing process method in improved sulfate soils with lime. It's also important to know that in sample No. 28 (9% lime & 9% gypsum) after 28 days that the samples is in protection under water, a layer of salt that Its approximate thickness is 4mm and cover 70% of surface sample, have appeared it was concluded that the reason of major swell in this sample and lack of specific rhythm with other results is because of this layer. The personality of this layer and reason of its existence is not clear for writers. And the important thing is the results of this examination.

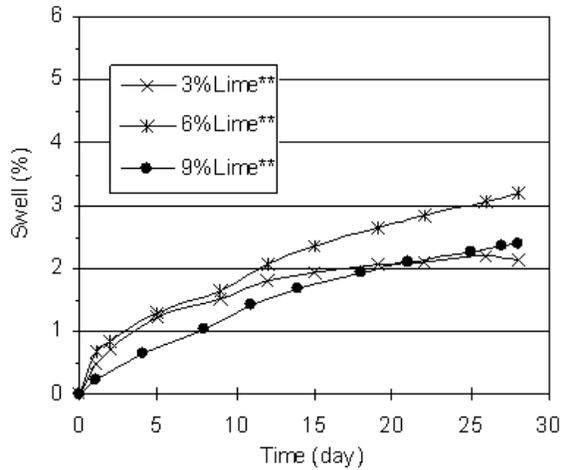


Fig. 9: The Swell-time curve for the samples with 6% gypsum in double process method

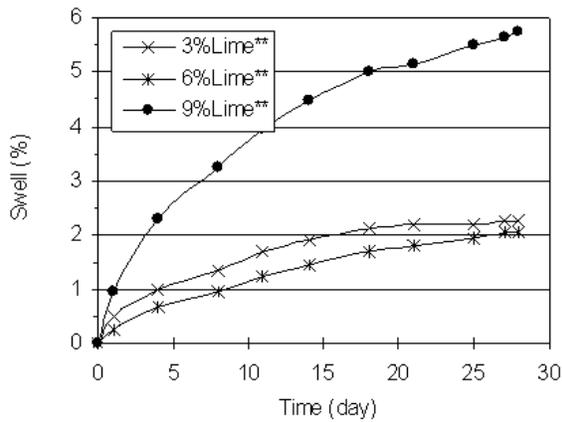


Fig. 10: The Swell-time curve for the samples with 9% gypsum in double process method

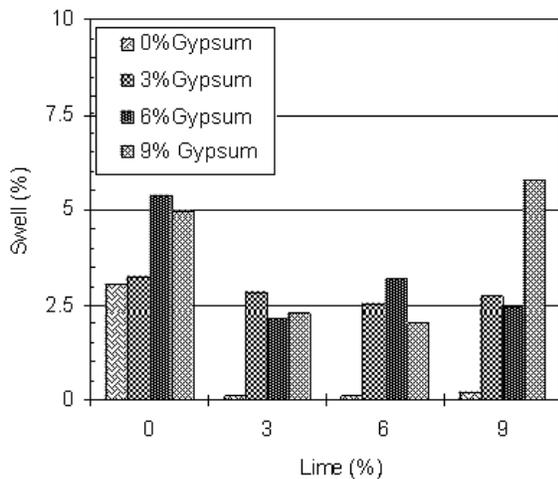


Fig. 11: Changes of swell rate inverse of different quantities of lime and gypsum in double process method

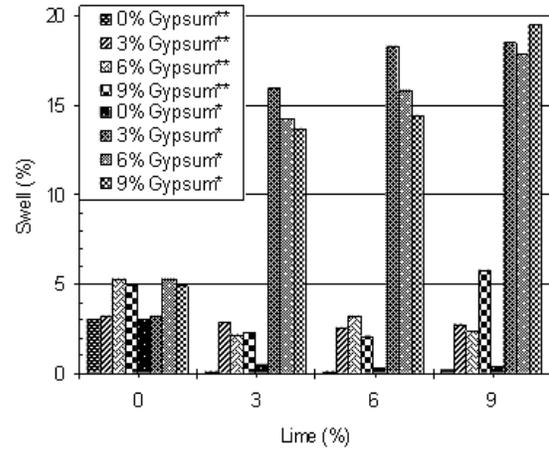


Fig. 12: Changes of swell rate inverse of different quantities of lime and gypsum - mixing method

Comparison of swell results in regular mixing method and double mixing process method: The Fig. 12 shows considerable affection of Double mixing process method in comparing with regular method in swell reduction. Also from result comparison we can see that regular method for gypsum soils beside prevent swelling reduction in comparison with unimproved soil, but increase that up to 14 or 20%, As in Double process method sample swell up to 3%.

In regular method after 28 days still swell permanently has continued but in Double process Method the rate of swell in later days decrease and swell came to maximum quantity of it. So we can conclude that the Double process method is in Times better than the regular method from swell aspect. And faster come with a permanent case. The Fig. 12 shows that in a same percent of gypsum Double lime Application cause a reduction in swell approximately 12 to 15% in comparison with regular method.

CONCLUSION

The lime roles instead of granule soils have been realized from ancient times. Chemical reactions, in an exchange between lime, Alumina and silica that exist in a clay cause increase in efficiency, reduction plastic index of soil and also pozzolanic reactions cause a cemented mass come into existence That its resistance is approximately high.

But in attendance of sulfates like calcium sulfate (gypsum) in soil beside pozzolanic reactions between clay and lime that cause silicate and calcium alumina to be made, but chemical reactions between clay, lime and sulfates cause to product expandable minerals like Ettringite and Thaumasite. These minerals at the water adjacent swell intensively and cause many damages like at the surface of the roads that the weight of the structure is light.

According to the researches by use of a kind of soil with low plasticity and It's mixed with different percents of gypsum and then its improvement by lime in two methods that already mentioned and Doing swell examination of them, the following results are achieved:

- * The attendance of sulfate in soil doesn't have any affection on momentary reactions between clay and lime.
- * Gypsum or watery calcium sulfate doesn't have any affection on soil swell lonely, but dry calcium sulfate (Anhydrite) causes swelling by absorbing of water.
- * Quantities of Ettringite and Thaumasite depend on the quantity of three parts that those minerals have made up of them; a means (clay, lime and sulfate) and also temperature; and it's not possible to define specific limitation by means of dangerous limitation of sulfate.
- * The presence of calcium sulfate even it's in low or high percent cause extreme rising in swell at the improved soil by lime in common method compares with unimproved soil.
- * Improving of sulfated soils (gypsums) by Double lime application cause reduction of swell compare with unimproved clay.
- * The swell in improved sulfated soils in regular method can continue until a long period of time. As in double process method soil come to a steady or permanent case sooner.

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